INFLUENCE OF CRYPTOGAMIC CRUSTS ON MOISTURE RELATIONSHIPS OF SOILS IN NAVAJO NATIONAL MONUMENT, ARIZONA

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Abstract.— Cryptogamic soil crusts of Betatakin Canyon in Navajo National Monument were investigated to understand the influence of such crusts on soil moisture relationships and potential sediment production. Crusts sampled were part of the pinyon-juniper community and were studied in paired units. The presence of crusts on soils significantly increased the depth of water penetration and decreased runoff. Soils showed reduced infiltration of water where lichen and algal crusts were present and enhanced infiltration rates where mosses were present. Crusts appear to cause surface sealing and therefore likely reduce surface evaporation rates as well.

Cryptogamic crusts are nonvascular plant communities that grow on or immediately beneath the soil surface. Such communities are components of most desert ecosystems. They have been described in several ecosystems in western North America (Anderson and Rushforth 1976, Anderson et al. 1982a) as well as in the deserts of the Middle East (Evenari et al. 1971). Until recently scant attention had been given them and little was known concerning their role in native ecosystems. Studies of the past decade indicate that they exert a significant impact on reducing soil erosion (Evenari et al. 1971, Loope and Gifford 1972, Kleiner and Harper 1972, Kleiner and Harper 1977, Anderson et al. 1982a, Anderson et al. 1982b). Fletcher and Martin (1948) found that fungal and algal crusts increase the tensile strength of soil. The algae appear to be the most effective in binding the surface soil particles (Durrell and Shields 1961) because of the thick gelatinous sheaths that enclose the trichomes of several algal species (Anderson and Rushforth 1976). Such gelatinous sheaths add strength and aggregating qualities to the 1 or 2 mm of surface soil upon which they grow (Anantani and Marathe 1974).

Research on the biology of cryptogamic crusts has also been done in several other areas. These studies include taxonomy (Ali and Sandhu 1972, Anderson and Rushforth 1976); nitrogen fixation (MacGregor and Johnson 1971, Reddy and Gibbons 1975); land reclamation (Singh 1950); soil fertility (Shields and Durrell 1964); reproduction, growth and habitat relations (Evenari et al. 1971, Anderson et al. 1982b); and moisture (Booth 1941, Loope and Gifford 1972).

The objective of this study was to investigate the influence of cryptogamic crusts in the pinyon-juniper woodlands of northeastern Arizona on depth of water penetration, infiltration, runoff, and potential sediment production.

Study Area

Navajo National Monument is located in northeastern Arizona (Fig. 1) and is the site of three large Anasazi Indian cliff dwellings. Betatakin Canyon, the site of the present study, is a side canyon of the larger Tsegi Canyon complex and has been described by Hack (1945). The major geological formation comprising the canyon is Navajo Sandstone, which forms sheer towering cliffs 200 m or more in height. The canyon floor consists of deep alluvial deposits of sandy Quaternary fill. Kayenta sandstone outcrops in the lower reaches of the canyon.

The annual temperatures recorded at the park headquarters weather station at Betatakin canyon ranges from –23 to 38 C with a mean of 10 C. The number of frost-free days in the area varies from 107 to 213, with an average of 155 days. Total annual precipitation ranges from 17 to 48 cm with a yearly mean of 29 cm. There is a single wet season lasting from late summer through fall.

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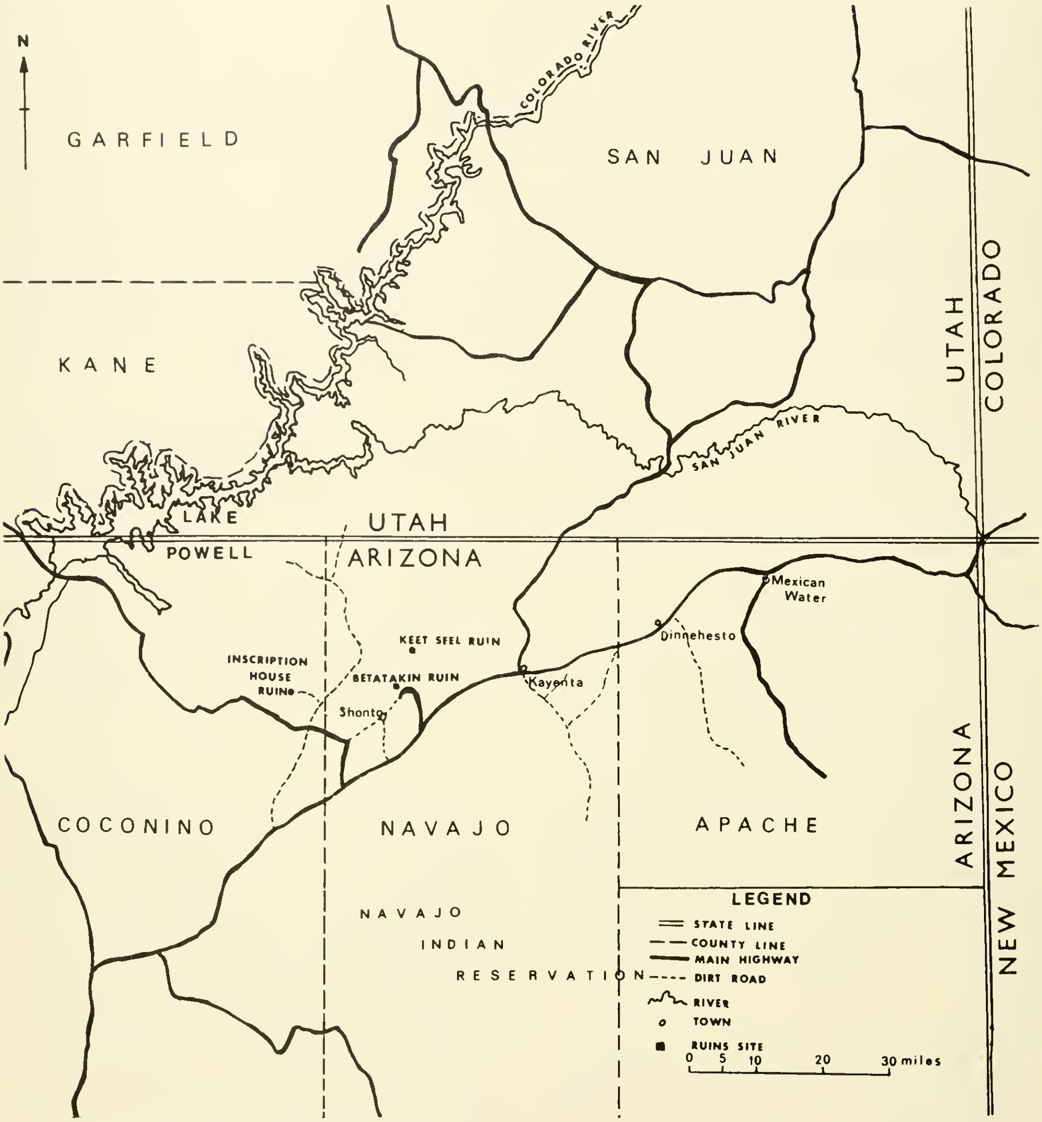


Fig. 1. Reference map of study area.

METHODS

Cryptogamic crusts were sampled in the pinyon-juniper (*Pinus edulis-Juniperus osteosperma*) community that borders Betatakin Canyon in Navajo National Monument, Arizona. Cryptogam crusts were studied in paired units so that varying conditions in habitat (slope, exposure, soil texture, etc.) could be kept to a minimum. Pairs consisted of five sites where crusts were intact and undisturbed and five adjacent sites where the crusts had been heavily disturbed or destroyed. A total of 10 sites were considered for each measurement. Pairs were always located within 2 m of each other.

Water infiltration rates were measured by using a thin-walled aluminum cylinder 12 cm tall and 65 mm in diameter. The cylinder was gently turned into the crust or soil to a depth of 2 cm and then 50 ml of water was ponded above the core inside of the cylinder. Infiltration into the core was measured as the number of seconds needed for the ponded water to disappear into the core.

Depth of water penetration and runoff were assessed by raining 1.5 liters of water onto the crust or adjacent soil surface through a perforated 80 mm diameter disk. The perforations were evenly spaced on a 0.5 cm grid. The disk was placed at a distance of 1.2 m above the ground surface. Total delivery time for the water to be dispensed onto the crust or soil surface was 60 seconds. These rates were designed to approximate or exceed precipitation at cloudburst proportions (i.e., 10 cm/hr). High intensities of precipitation, such as those exceeding infiltration capacities of the soil, are significant because of their effects on runoff and erosion. Once the water had disappeared into the crust or soil surface, depth of penetration was measured immediately. Five depth measurements were taken for each watering at each of the 10 areas and then averaged to give a single value for each site.

Runoff was measured by recording the across slope and downslope spread of water rained onto study sites. The area of spread was computed from these measurements using the formula for the area of an ellipse.

Soil movement was assessed by estimating the amount of soil moved during a measured rain. The following index was used: 1 = no appreciable movement; 2 = moderate movement—up to 10 percent of soil being displaced; and 3 = heavy movement—between 10 and 20 percent of soil being displaced.

All runoff and soil movement measurements were taken during the third week of August 1980. Sampling intensity was determined following the estimation procedures described by Avery 1975. Significant differences in the paired measurements were assessed through the use of Students-t statistic.

Results and Discussion

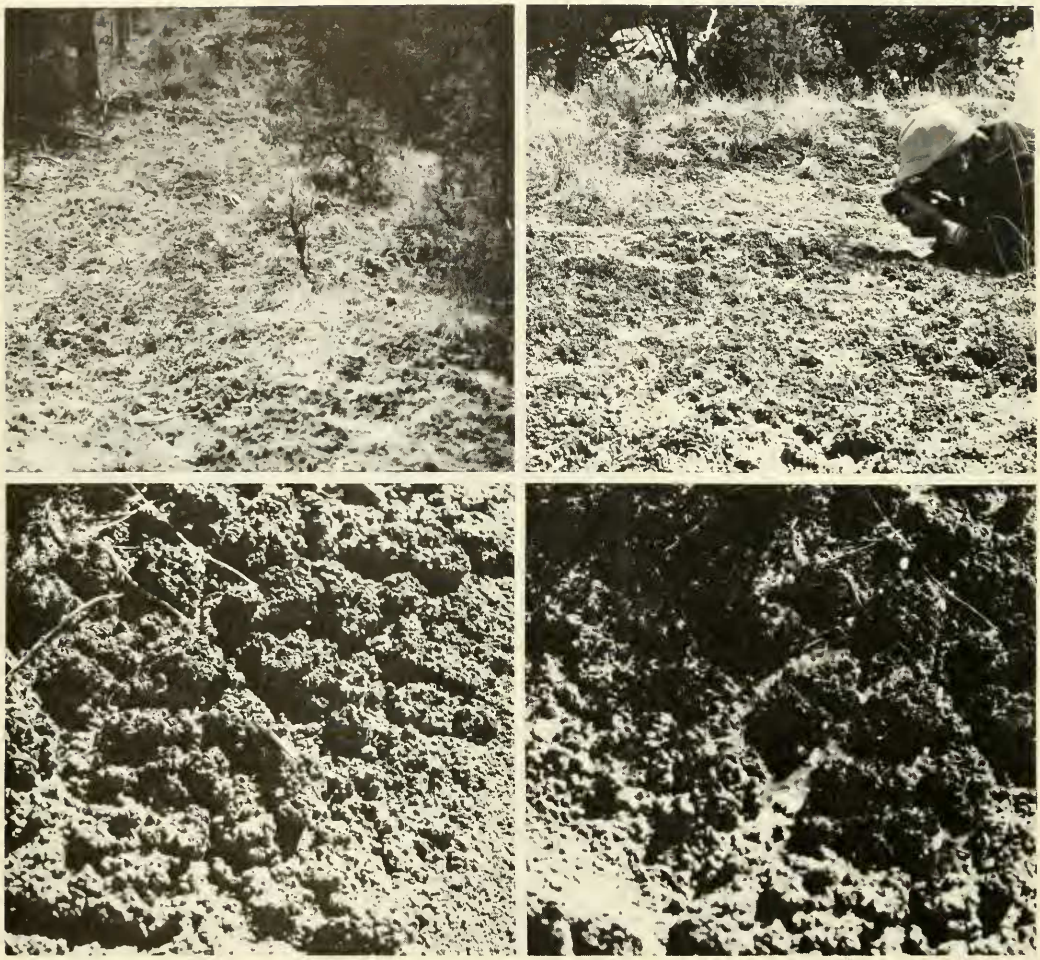
The influence of cryptogamic crusts on six soil moisture characteristics was assessed. Average values for all measurements taken during this study are given in Table I. All but one of the measured characteristics showed significant differences between crusted and uncrusted soils.

Infiltration measurements on the paired study sites indicated that well-developed cryptogamic crusts (Fig. 2) significantly increased the depth of water penetration. This was also found by Loope and Gifford (1972). Downslope movement of water was significantly greater on the sites that exhibited no crust development. Likewise, the differences in total area of surface spread was significantly greater on uncrusted soils. These differences are probably best explained by the micro-topographic changes that develop at the soil surface under the influence of cryptogamic crust growth. Well-developed crusts form pedestals so that the ground surface looks something like a convoluted brain coral (Fig. 2-4). Hills and valleys a few centimeters in relief develop across broad crusted areas. The small valleys run in all directions and cause pooling of the water as it hits the soil surface (Fig. 5). This pooling holds the water in place for extended periods, thus increasing the time for infiltration to occur and simultaneously decreasing runoff and movement across the soil surface. With reduced surface movement, deeper penetration of water occurs. The net effect is to slow the movement of surface-flowing water, providing longer periods for infiltration, less opportunity for

Table 1. Relationships of cryptogamic crusts growing on the soil in Navajo National Monument to measured moisture parameters. Figures represent means and standard deviations (sd).

Characteristic measured	Crust		Noncrust		Significance level
	Mean	sd	Mean	sd	
Water penetration depth (cm)	5.46	1.35	3.23	0.69	.05
Downslope spread (cm)	67.62	13.74	95.50	4.24	.001
Across slope spread (cm)	47.24	10.87	45.72	6.48	NS
Area of spread (sq cm)	10434.11	3041.18	13738.50	2185.26	.001
Soil movement*	1.00	0.00	2.60	0.89	.01
Infiltration (seconds)					
Moss cover	15.40	3.90	238.00	87.90	.001
Lichen and algae cover	48.00	14.50	31.00	8.10	.001

*Soil movement was assessed as follows: 1 = no movement, 2 = moderate movement—up to 10 percent of soil being displaced, 3 = heavy movement—between 10–20 percent of soil being displaced.



Figs. 2–5. Cryptogamic crusts. Left top, moving clockwise: 2. Crusts beneath Utah juniper trees. 3. Well-developed cryptogamic soil crusts. 4. Close-up of cryptogamic crusts showing typical pinnacle development. 5. Close-up of cryptogamic crust after experimental rain showing water ponding.

concentration in rills, and decreased power to cause erosion. In other words, cryptogam crusting fosters more infiltration and less runoff of surface water.

Well-developed crust areas also showed significantly less soil movement (Table 1). These data support the findings of several other studies (Fletcher and Martin 1948, Loope and Gifford 1972, Kleiner and Harper 1977, Anderson et al. 1982b). Cryptogamic crusts appear to have a protective influence on the soil in four major ways. First, they bind the soil surface particles with the intertwining growth of algal and fungal filaments (Durrell and Shields 1961). Second, the moss and lichen constituents of cryptogam crusts aid in stabilizing the soil by covering the surface with thalli and penetrating the soil surface with rhizoids (Anderson et al. 1982b). Third, the irregularities of a well-developed cryptogamic crust surface tend to break up microwind patterns and thus reduce windborn soil movement (Brady 1974). And fourth, with less water movement there is also significantly less soil movement.

Well-developed crusts also influenced water movement into the soil. Where moss cover was high, infiltration rates were greatly enhanced over areas where moss cover had been removed. The enhancement of infiltration appeared to be due to the moss thalli acting as a sponge. On the other hand, where they had been removed, a .05 to 1 cm thick layer of silt beneath them acted to retard infiltration. Infiltration rates were significantly reduced or impeded by lichen and algal crust cover. The highest infiltration rates (most rapid penetration by water) occurred on soils with no cryptogamic cover (Table 1). In general, where cryptogamic cover was high, increased resistance to infiltration occurred. Loope and Gifford (1972) noted this pattern and also found that, when crusts were wetted previous to infiltration trials, infiltration rates on crusted soils were retarded by a factor of two. Fritsch (1922) first suggested that the highly mucilaginous sheaths of blue-green algae, which are the major components of cryptogamic crusts in arid environments, might form a layer at the soil surface that would both impede water infiltration into the soil and impede evaporation of soil moisture caught beneath the algal layer. This would provide more water to the plants growing in such areas. Booth (1941) later tested this hypothesis and showed that more moisture was to be found in the upper layers of soil (i.e., the upper 2.5 cm) where cryptogamic crusts were prominent than in adjacent soils with no crusts (i.e., 8.9 percent vs. 1.3 percent, respectively).

Data from several studies indicate that high cryptogamic crust cover is associated with high silt in the soil surface (Evenari et al. 1971, Loope and Gifford 1972, Kleiner and Harper 1977, Anderson et al. 1982b). Textural observations on our sites showed similar patterns. Kleiner and Harper (1977) also argue that once established the crusts tend to trap silt at the soil surface. Evenari et al. (1971) and Blackburn and Skou (1974) present data that indicate that soils high in silt often have low permeability rates and high runoff. They suggested that soils with high levels of silt in the upper layers often show high initial infiltration rates, but, as more wetting occurs, the percolation rates decrease rapidly and eventually an almost impenetrable layer can be formed. Beneath such a sealed surface, air caught in the voids of the lower layers may have a difficult time escaping and may therefore further retard infiltration (Evenari et al. 1971).

It appears then that at least three factors tend to reduce water infiltration rates in soils with cryptogam crusts: (1) the effect of high levels of silt in the soil and its resultant swelling and sealing action when mixed with water (Evenari et al. 1971); (2) the wetting action of the water on the gelatinous sheaths of the algal filaments, causing the filament to swell and tightly bind the surface soil particles (Anantani and Marathe 1974, Durrell and Shields 1961, Fritsch 1922); and (3) air trapped beneath the sealed surface to further impede water penetration.

Evenari et al. (1971) also indicated from their research on micro-watershed irrigation projects that, as the farm areas receive runoff water ladened with silt from the watersheds and as the silt is deposited on the soil surface, evaporation from the irrigated fields was reduced to as little as 7.4 mm over a seven month period. This kind of reduction in evaporation in a desert with annual evaporation values from 1700 to 2700 mm would be highly important relative to moisture retention in the subsurface layers of the soil.

Since cryptogamic crusts tend to seal the soil surface and since crusts also increase the depth of water penetration, the effects they have on reducing moisture stress in desert ecosystems could prove to be extremely valuable. Furthermore, since crust communities tend to grow in association with high silt levels at the soil surface, these elevated silt levels undoubtedly further reduce water losses by evaporation. This being the case, cryptogamic crusts may be as important in their role in water conservation in desert systems as they are in preventing soil erosion.

Literature Cited

Ali, S., and G. R. Sandhu. 1972. Blue-green algae of the saline soils of the Punjab. Oikos 22:268–272.

Anantani, Y. S., and D. V. Marathe. 1974. Soil aggregating effects of some algae occurring in the soils of Kutch and Rajasthan. Univ. of Bombay 41:94–100.

Anderson, D. C., K. T. Harper, and S. R. Rushforth. 1982a. Recovery of cryptogamic crusts from grazing on Utah winter ranges. J. Range Manage. 35:355–359.

Anderson, D. C., K. T. Harper, and R. C. Holmgren. 1982b. Factors influencing the development of cryptogamic soil crusts in Utah deserts. J. Range Manage. 35:180–185.

ANDERSON, D. C., AND S. R. RUSHFORTH. 1976. The cryptogamic flora of desert soil crusts in southern Utah. Nova Hedwigia 29:691–729.

AVERY, T. E. 1975. Natural resources measurements. 2d Ed. McGraw-Hill Book Company, New York. 339 pp.

BLACKBURN, W. H., AND C. M. SKOU. 1974. Infiltration rates and sediment production of selected plant communities in Nevada. J. Range Manage. 27:476–479.

BOOTH, W. E. 1941. Algae as pioneers in plant succession and their importance in erosion control. Ecology 22:38–46.

BRADY, N. C. 1974. The nature and properties of soils. 8th ed. Macmillan Publishing Co., Inc., New York. 639 pp.

DURRELL, L. W., AND L. M. SHIELDS. 1961. Characteristics of soil algae relating to crust formation. Trans. Amer. Micro. Soc. 80:73–79.

EVENARI, M., L. SHANAN, AND N. TADMOR. 1971. The Negev—the challenge of a desert. Harvard Univ. Press, Cambridge, Massachusetts. 345 pp.

FLETCHER, J. E., AND W. P. MARTIN. 1948. Some effects of algae and molds in the rain-crust of desert soils. Ecology 29:95–100.

FRITSCH, F. E. 1922. The terrestrial algae. J. Ecology 10:220–236.

HACK, J. T. 1945. Recent geology of the Tsegi Canyon. Appendix 1 *in* R. L. Beals, G. W. Brainerd, and W. Smith, eds. Archaeological studies in Northeast Arizona. Univ. of California Press, Berkeley and Los Angeles.

KLEINER, E. F., AND K. T. HARPER. 1972. Environment and community organization in grasslands of Canyonlands National Park. Ecology 53:229–309.

______. 1977. Soil properties in relation to cryptogamic ground cover in Canyonlands National Park. J. Range Manage. 30:202–205.

LOOPE, W. L., AND G. F. GIFFORD. 1972. Influence of a soil microfloral crust on select properties of soils under pinyon-juniper in southeastern Utah. J. Soil and Water Conser. 27:164–167.

MACGREGOR, A. N., AND D. E. JOHNSON. 1971. Capacity of desert algal crusts to fix atmospheric nitrogen. Soil Sci. Soc. of Amer. Proc. 35:843–844.

REDDY, G. B., AND J. GIBBONS. 1975. Nitrogen fixation by algae on fescuegrass soil crusts. Soil Sci. of Sco. Amer. Proc. 39:654–656.

SHIELDS, L. M., AND L. W. DURRELL. 1964. Algae in relation to soil fertility. Bot. Rev. 30:92–128.

SINGH, R. N. 1950. Reclamation of "Usar" lands in India through bluegreen algae. Nature 165:325–326.